The most pervasive sounds from underwater detonations occur at low frequencies. In deep water, low frequency sounds from a detonation peak at about 15 Hz (Richardson *et al.* 1995). In shallow water, however, very low frequency sounds can be reflected off the sea floor, resulting in somewhat higher frequency sounds becoming more dominant. For example, during the recent decommissioning of the Mobil Seacliff Pier Complex, which was in similarly shallow water, the low frequency sounds ranged from 25 to 800 Hz, with an average of 269 Hz (Howorth 1998c through e).

Little information is available on pile-driving sounds; however, it appears that such sounds can range from 20 Hz to over 25 kHz (Richardson *et al.* 1995; Würsig *et al.* 2000). It is likely that the frequency spectrum is even broader at the source. The most pervasive sounds at a distance are lower frequency sounds ranging from 20 to 800 Hz (Richardson *et al.* 1995; Würsig *et al.* 2000).

6.5 Estimating and Measuring Sound Pressure Levels and Frequencies

As explained earlier, sound pressure waves cause sudden overpressures. The extent of this overpressure can be assessed by estimates, computer modeling or actual measurements in the field. Although no estimates have been made for pile driving sounds for this project, some estimates were made for the detonations. One set of estimates was based on open water detonations, while the other was based on charges buried in mud (Leidel 1999). These estimates are presented below:

TABLE 8: SOUND PRESSURE LEVELS FROM TNT EQUIVALENT LIQUID CHARGES

Charge Size	Range	Mud-buried Peak (psi)	Open Ocean Peak (psi)
7.2 pounds	100 feet	80.8	260.1
7.2 pounds	150 feet	50	164.5
7.2 pounds	200 feet	35.6	118.8
7.2 pounds	250 feet	27.4	92.4
7.2 pounds	300 feet	22.1	75.2
7.2 pounds	350 feet	Not calculated	63.1
7.2 pounds	400 feet	15.7	54.3

Source: Leidel 1999

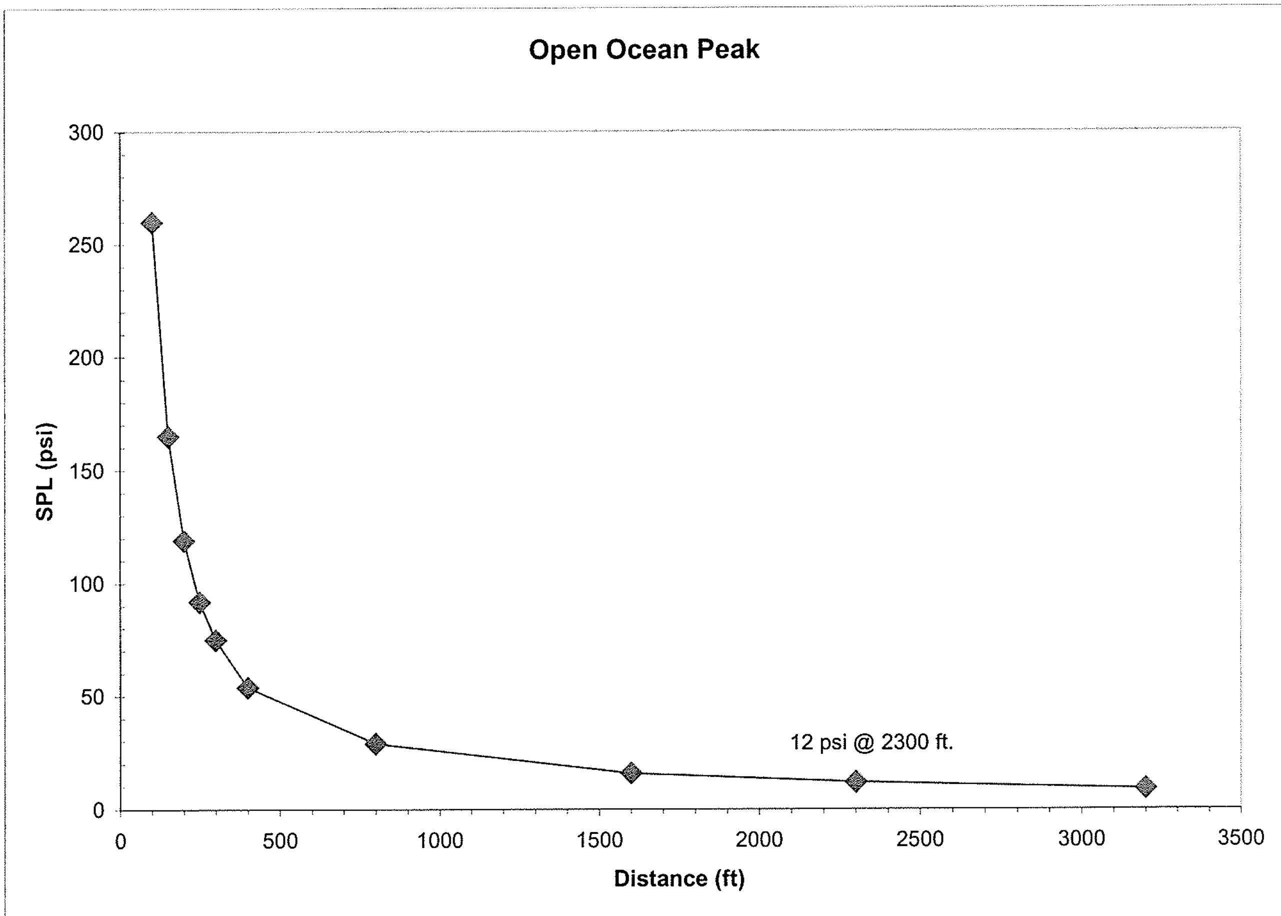
One difficulty with these estimates is that they were made for mud-buried and open ocean charges, neither of which is directly applicable to the explosives deployment strategy planned for this project. Mud-buried charges represent a best-case scenario because mud considerably dampens the energy of a detonation. In a sense, open-ocean charges represent a worst-case scenario because the detonation is coupled directly to the water column. However, as discussed earlier, in shallow water, reflected sound waves sometimes converge in phase, creating a stronger sound pulse at a given distance. The calculations do not allow for shallow water effects. If convergence does not occur, the values would likely fall somewhere in between the estimates for mud-buried and open-ocean charges, probably slightly toward the mud-buried levels because the charges would be detonated inside the crater produced by the excavation. The crater would help absorb and reflect sounds, as would the mass of concrete immediately

738

above the detonations. Jetted material built up on the ocean side of the columns would also help reflect and absorb sounds. Finally, by setting off the seaward charges first, the bubbles from the detonations and mass of the columns would absorb and reflect the sounds of subsequent detonations.

The estimates assume that all four charges in a set will be detonated simultaneously, which will not be the case unless the charges detonate sympathetically. Thus, in that sense, all of the estimates represent a worst-case scenario.

Also, the estimates were not carried to the 12-psi threshold. Below is a graph that projects the range (2300 feet) at which the 12-psi threshold is reached with all four charges detonated simultaneously in the open ocean. On the next page, the table

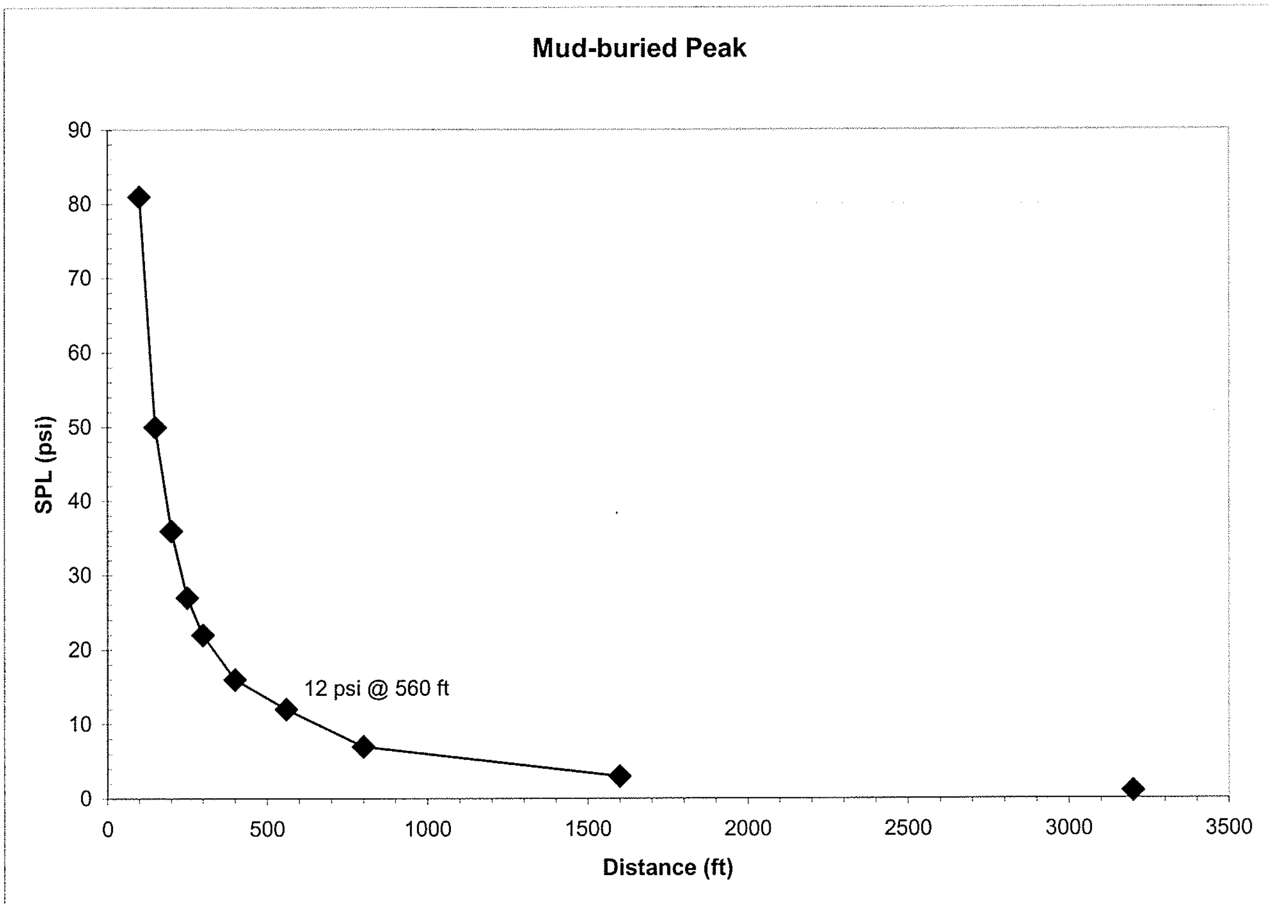


indicates that the threshold for mud-buried charges is reached at a range of approximately 560 feet.

Since the detonations for this project will occur in rapid succession, measurements of sound pressure levels would have no mitigation value for this project because the data would be obtained after the fact. Measurements in the field are useful for determining

739

the accuracy of estimates or models when repeated detonations are necessary over time, however. Such measurements are made by recording the sound levels at various



distances, depths and directions from the detonation site. Typically, recordings are made from hydrophones—undersea microphones—linked to digital audio tracking (DAT) recorders. The recordings are then analyzed and received sound pressure levels within the frequency ranges of the equipment are noted. In this way, the threshold limits and dominant frequencies can be assessed at various distances, depths and directions from a detonation site.

Prior to a recent pile-driving project on the beach at Lease 421, Greene (2001a and b) conservatively estimated that a sound pressure level of 160 dB re 1µPa - rms would be attained at a range of 374 feet. A hazard zone of 500 feet was employed for that project. The project involved 12-inch piles driven with a small hammer into beach sand. To make his estimates, Greene applied sound pressure measurement data taken during a pile driving operation for a fueling facility at the Hong Kong Airport (Greene 2001a and b). In that project, piles were driven into the substrate in 20 to 26 feet of water depth. Pile specifications were not provided by Wursig *et al.* (2000). However, since the piles were driven into hard substrate, it is safe to assume that hollow steel piles rather than solid wooden ones were used. In the Hong Kong project, the pile driver produced approximately 90 kilojoules of energy (Wursig *et al.* 2000). Measurements were taken 820 feet (250 meters), 1,640 feet (500 meters) and 3,281 feet (1000 meters) from the

540

pile driving site. The frequency range of the measurements was 100 Hz to 25.6 kHz. The loudest sounds heard at 3,281 feet were approximately 152 dB re 1μPa. Highest sounds were recorded 820 feet from the pile driving operation. These sounds measured approximately 170 dB re 1μPa.

6.6 Sound Pressure Levels from Past Projects

During the recent Mobil Seacliff Pier Decommissioning Project, northwest of Ventura, California, 21 caissons were removed. The caissons were made of steel-reinforced concrete anchored into bedrock. They varied from 8 to 22 feet in diameter. The caissons ranged from the intertidal zone out to approximately 30 feet of water. They had to be shattered using large amounts of explosives—from 88 to 595 pounds per caisson, for a total of about 3000 pounds of explosives (Howorth 1998c through e).

Sound pressure levels were measured at various depths and distances from several detonation sites. The maximum peak sound pressure level at 1000 yards was 202.8 dB re 1μPa, considerably above the threshold level accepted at the time (180 dB re 1μPa). For this reason, the hazard zone for that project was extended to 3000 yards. Part of the reason for the high sound levels was that the concrete was in very bad condition. Instead of absorbing much of the energy, the deteriorated concrete allowed the release of a considerable amount of energy into the water column.

For this project, individual charge weights will be only 1.8 pounds. In the unlikely event that more than two charges detonate at once, the maximum weight of a set of charges will be only 7.2 pounds. The total amount of explosives for the entire project will be 57.6 pounds, compared to nearly 3000 pounds for the Mobil Seacliff Pier Project. The Mobil project represented an extreme case, yet it was carried out with no impacts to marine mammals (Howorth 1998c through e).

For this project, linear shaped charges will be used. Such charges are designed to channel most of the energy inwards to sever the steel H-piles. This eliminates the uncertainties involved with deteriorated structures demolished with internal charges.

6.7 Bubble Curtains

Some planners believe that bubble curtains help reduce fish kills by frightening fish away from a detonation site. However, when resident benthic fish are frightened, they generally take refuge in familiar surroundings, thus a bubble curtain could have the opposite effect on such fish (Howorth 1998c through e). Also, bubble curtains displace water toward the surface as the bubbles rise, bringing a plume of nutrients to the surface that may actually attract small pelagic fish.

6.8 Wildlife Hazard Zones

For most past projects involving explosives in this region, a 1000-yard hazard zone has been considered adequate for the protection of marine mammals. During the removal of four of Chevron's oil platforms off Santa Barbara, California (Howorth 1996a and b), 45-pound targeted charges were detonated below the mudline to sever steel pilings used to anchor the platforms. In a project involving the removal of a Chevron wellhead off Ventura, California, a single 35-pound charge was used below the mudline (Howorth 1997a). In both cases, a 1000-yard hazard zone was used.

JHL

When an ocean riser platform off San Diego was removed, a 417-yard (1250 feet) hazard zone was considered adequate. In this case, 4.6-pound charges were deployed. The platform had been used to install a huge offshore sewer line as part of a joint American-Mexican project near the border (Howorth 1997b).

No significant impacts to marine mammals were observed during these projects. Considering the small size of the charges for this project and the worst-case scenarios presented in the estimates, a 1000-yard hazard zone would offer sufficient protection for marine mammals during detonations.

A 1000-yard hazard zone is also proposed for pile driving operations. This is based on sound pressure level measurements taken during the Hong Kong pile driving project. As more information becomes available, this hazard zone may be revised.

J42